Measurement of *in situ* Permeability of Sandy Sediments

H. Paul Johnson
University of Washington, School of Oceanography
Box 357940, Seattle, WA 98195-7940
phone: 206-543-8474 fax: 206-543-0275 email: johnson@ocean.washington.edu

Award Number: N00014-98-1-0031

LONG-TERM GOALS

The primary goal for this project was to identify the geological processes that control the physical properties of sediments in the shallow water marine environment. Through alteration, cementation, precipitation and biological activity, fluid flow within sediments controls many of the important physical properties that impact the acoustic response of that media, and our ability to characterize sediment permeability is critical to understanding that relationship.

OBJECTIVES

To pursue the above objective of understanding the role of fluid flow within the upper sediment column, it is necessary to make *in situ* measurements of permeability. Laboratory measurements of permeability are fundamentally changed from their *in situ* values due to coring disturbance, removal of overburden loading, and the dramatic reduction in scale-size for the measurement. *In situ* measurements of permeability, while having the potential of being much more accurate and representative of the sediment column, are extremely difficult to make. Further, sediment permeability depends on porosity, tortuosity of the channels, and void geometry, and can vary over many orders of magnitude even for the same sediment type.

APPROACH

The University of Washington has developed an instrument for the *in situ* measurement of the physical properties of the upper meter of sediments, including compressive wave velocity, density and permeability. This instrument was specifically designed for deployment during the ONR/DRI High Frequency experimental site, off Panama City, Florida. Working with SEAPROBE (Dr. Richard Bennett) who designed and constructed the permeability sensor, we developed the capability for making *in situ* measurements of permeability in the area of the DRI experimental site using the UW sediment physical properties tripod. This tripod was deployed in a 3-sided box (the 4^{th} side contained both anomalous relief and a different sediment type) around the DRI experimental site during the October, 1999 field season. During this deployment, 19 stations, measuring sediment permeability as a function of depth in the top 1 meter, were successfully completed.

The permeability sensor uses the tripod seawater pumping system to overpressure the pore fluid in the sediments, and measures the pressure and resulting flow rate at the probe tip. These two parameters can then be translated to effective in situ permeability. By using the UW tripod drive to insert the probe into the sediments by calibrated incremental distances (0 to 0.75 meters), it is possible to measure the variation of permeability as a function of depth within the sediment column. Previous

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Measurement of in situ Permeability of Sandy Sediments**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington, School of Oceanography,,Box 357940,,Seattle,,WA,98195**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

studies have shown that surface sediments are both extremely porous and permeable, with a logarithmic variation with increasing depth due to compaction.

WORK COMPLETED

The basic UW tripod was completed in 1998 and the capability of measuring compressional wave velocity (at 12 kHz and 3.5 kHz and 3rd harmonics of these frequencies) and in situ bulk density was successfully tested with several small boat cruises in Puget Sound. The equipment was shipped to Panama City, Florida in the summer of 1999, to be used as a site survey instrument, in order to locate an area of uniform sandy sediments for the DRI experiments. Shipping problems (the main motor for the tripod drive did not arrive until 20 hours before the end of the cruise) prevented extensive deployment of the tripod, although in this limited time, the tripod was successful in locating layers of carbonate shells within the upper sediment layers at the (initial) primary site off Panama City. The assigned task of the UW tripod was then redefined to consist entirely of making *in situ* permeability measurements to support the acoustic studies within the DRI experiment. To this end, in October, 1999 we deployed the tripod at 19 stations surrounding the DRI High Resolution experimental area, and focused on the analysis of that resulting data set. The preliminary analysis of the data acquired in that field program has now been completed by us, and a full error analysis of the permeability data has been carried out in our laboratory.

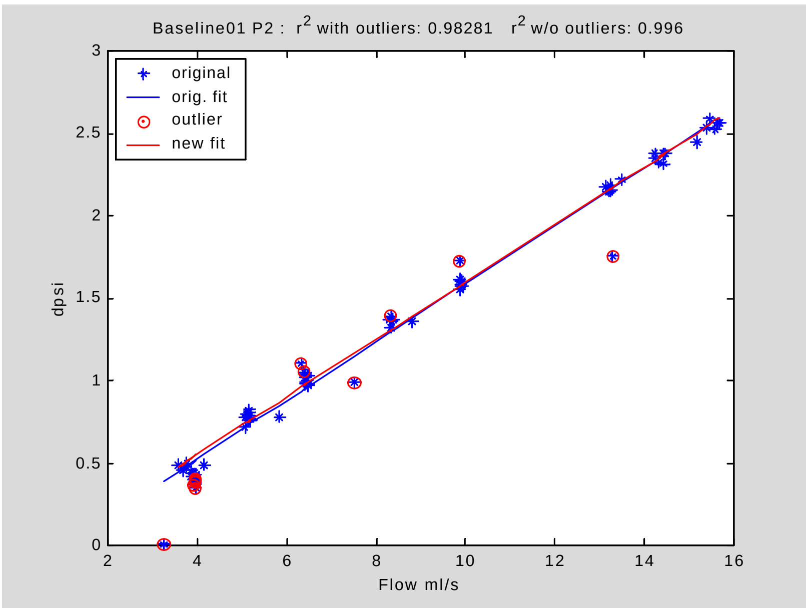
The UW Tripod consists of a large (14 ft x 14ft) metal frame with lead-weighted feet, data logger, power supply, pump, camera system, drive motor and screw. An optical encoder coupled to the drive shaft allows accurate (+/- 0.5cm) positioning of the measuring tool, with real-time two-way communication provided via a hard wire connection to the surface using RS232 protocol. Sediment permeability is determined by measuring differential pressure at two points on a probe inserted in the sediment. Differential pressure is measured using two Validyne DP215 pressure transducers, with accuracy is +/- 0.25% FS using a magnetic stainless flat diaphragm clamped between stainless case halves. Pick-off coils, embedded in the case halves, sense diaphragm deflection and deliver a full scale output of 35 millivolts per volt at 3,000 Hz, which are then digitized to 12 bit accuracy as A-to-D counts by an on-board computer. Diaphragm sensitivity at the output stone is 0-5 psi, while sensitivity at the passive stone is 0-0.125 psi. Calibration of A-to-D counts to psi was completed in the UW laboratory prior to use in the field, with the data being linear for each diaphragm.

The flow rate of fluid expelled at the output stone is monitored using an Omega FTB603 paddle-wheel flowmeter rated over the range of 8-250 ml/sec. This device uses an infrared electro-optical transmitter and receiver molded into the flowmeter's body along with two miniature circuit boards to provide voltage stabilization and automatic IR output level control. The unit automatically compensates IR light intensity for varying fluid opacity levels and outputs a square wave signal with an accuracy of +/- 1%, which is digitized to 12 bit accuracy as A-to-D counts by an on-board processor. Calibration of A-to-D counts to ml/sec was completed in the UW laboratory prior to use in the field, with the data being linear over the listed range as well as from 3-8 ml/sec.

Given flow rate and differential pressure at the output stone, the permeability of the sediment in contact with the output stone can be calculated using a 'constant head' method. The permeability in the region between the two stones can be calculated using a 'gradient' model. Prior to insertion of the probe into the sand, a 'baseline' suite of measurements was made with the tripod sitting on the seafloor. These measurements indicated the permeability of the system itself (k'), which decreased during the course of the field experiments as the stones and fluid filter collected small amounts of debris. Measurements consisted of increasing the flow rate at the output stone in four separate steps ranging

from 0-20 ml/sec while differential pressure and flow were recorded every 1.36 seconds. Each of the four flow rates was maintained for approximately twenty-one seconds, resulting in fifteen independent differential pressure measurements for each rate. In order to insure that measurements were within the operational range of the transducers, an offset voltage was applied and later corrected for.

Following insertion of the probe in the sediment, transducer output was monitored to verify dissipation of the pressure field due to the introduction of the probe itself, which occurred within seconds. These measurements yielded the effective permeability (k_e) of the tripod/sediment system. Data processing began by converting A-to-D counts to flow, temperature, and pressure using calibration curves determined in the lab. The data were then cleaned by removing outliers from the P2 (output stone) psi vs flow data, where each change in flow should have a corresponding change in differential pressure. Data points showing minimal/no change in differential pressure with increasing flow were removed.



.

Regression lines were calculated through the flow vs dpsi data at a 95% confidence interval for both the baseline and effective measurements. Two other regression lines were also placed within the limits of the 95% confidence interval in order to conservatively estimate measurement uncertainty. Error due to flowmeter and transducer uncertainty was also calculated, and total uncertainty was calculated using the Root Mean Squares method (square root of the sum of the squared error for each : measurement, flowmeter, transducers). Final permeability was calculated using the following equations, with final uncertainty being the square root of the sum of the baseline error squared and the effective error squared.

$$k_e = kk'/(k + k')$$

$$\frac{k_e - k}{k} = \frac{-1}{1 + k'/k}$$

k = permeability of the sediment

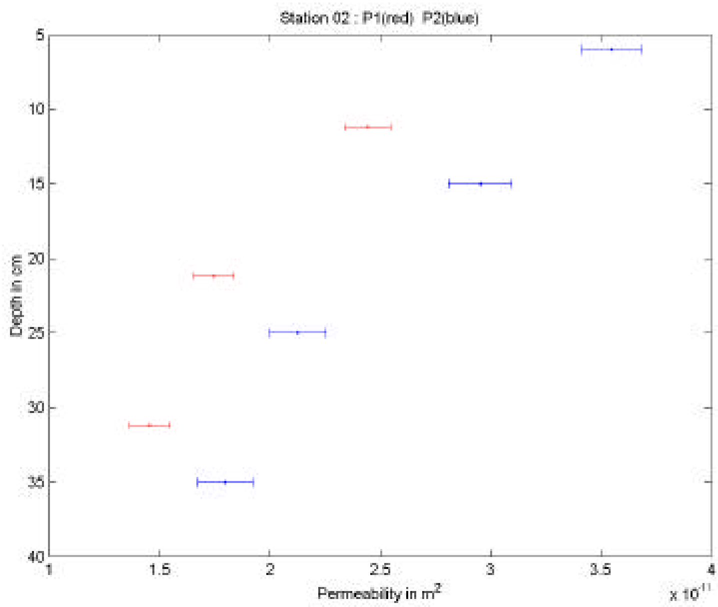
k_e = effective as measured by permeameter

k' = permeability of instrument (probe)

Therefore $k = k_e k' / (k'-k_e)$

RESULTS

While analysis of the data is still continuing, values of permeability of the surface sediments varied by a factor of 10 over the field site, with some areas having strong vertical gradients, while other sites showing relatively constant values as a function of depth. Gradient (P1) and active port measurements (P2) give slightly different values for the same depth due to different sampling zones for the two techniques.



On-going work in our laboratory is now attempting to define the physical and chemical processes that are responsible for the observed variations in permeability over the DRI site.

IMPACT/APPLICATIONS

Accurate and direct measurements of permeability in the upper sediment column have not been done previously, and will be useful for models of the acoustic properties of this important environment for the DRI program. Perhaps more significantly, the development of the capability to make these critical new measurements will have a major impact on our understanding of fluid flow in the upper sediment column. Although speculative, this is likely to lead to a new realization that previously unappreciated processes such as tidal and storm forcing play a major role in the physical properties of shallow marine sediments.